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Thermal Performance Analysis of Space Heating Systems in the National Solar Data Network

July, 1979

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U.S. Department of Energy

National Solar Heating and Cooling Demonstration Program

National Solar Data Program

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THERMAL PERFORMANCE ANALYSIS OF SPACE HEATING SYSTEMS IN THE NATIONAL SOLAR DATA NETWORK

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HUNTSVILLE, ALABAMA

PRESENTED AT THE U. S. DEPARTMENT OF ENERGY'S
REGIONAL SOLAR UPDATES 1979

PREPARED FOR
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CONSERVATION AND SOLAR APPLICATIONS
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H. JACKSON HALE, PROGRAM MANAGER

ABSTRACT

Space heating applications account for a significant portion of the national demand on energy supplies. This paper presents a summary of the performance of several solar energy space heating systems in the National Solar Heating and Cooling Demonstration Program. The solar energy utilization is depicted graphically, along with the identification of system losses. In addition, problems which appear to have the most severe impact on system performance are described.

The paper includes a table summary of all space heating systems being monitored, and the characteristics of each.

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2. SPACE HEATING SOLAR ENERGY SYSTEMS IN THE NSDN

The National Solar Heating and Cooling Demonstration Program provides a framework in which a large variety of solar energy systems may be evaluated. As a part of this major program, the National Solar Data Network collects instrumented data from many of the systems. Of the more than 100 systems now being monitored, there are 84 which provide space heating. Forty-two of these are residential applications, the remainder being commercial applications, including some apartment buildings. These systems were selected to provide a wide distribution across the contiguous 48 states. See Figure 2-1.

Figure 2-1. NATIONAL DISTRIBUTION OF SPACE HEATING SYSTEMS

Sixty percent of the 84 systems being monitored employ liquid flat-plate collectors, 10 percent are liquid concentrating collectors, and five percent are liquid evacuated tube collectors, as illustrated in Figure 2-2. All of these use water as the storage medium, with the exception of one which has no storage. The remaining 25 percent of the systems use air flat-plate collectors coupled with rock bin storage, again with one exception, which has no storage capability.

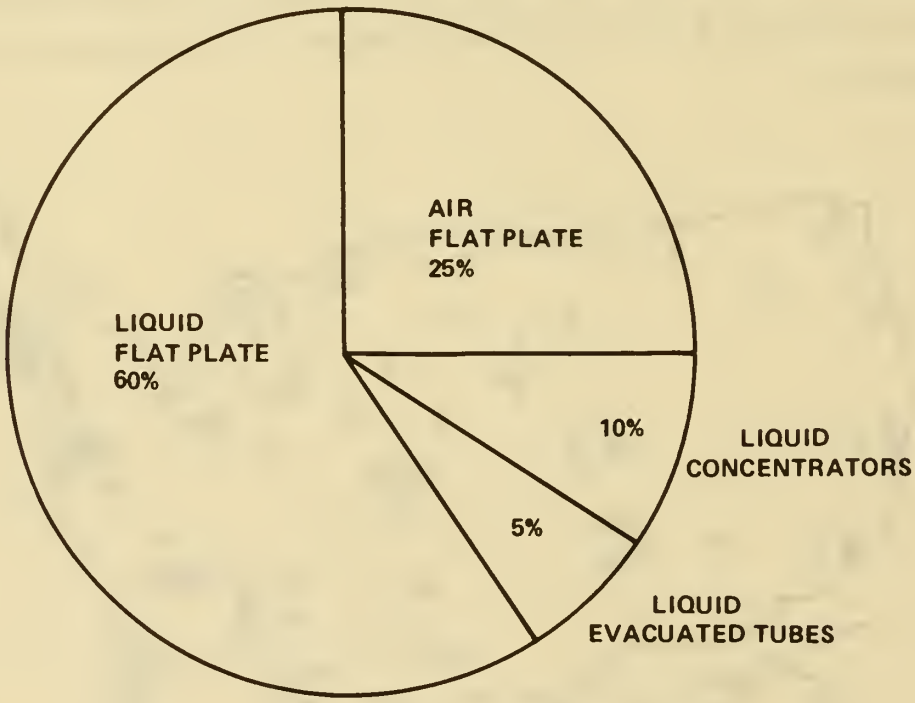

Figure 2-2. DISTRIBUTION OF COLLECTOR TYPES

The locations and characteristics of all 84 heating systems are presented in Appendix A. The features identified include collector type, area, and manufacturer, storage medium and volume, and the source of auxiliary heating energy.

3. REVIEW OF PERFORMANCE OF SELECTED SYSTEMS

The basic goal of solar energy heating systems is to transform and transmit energy from the sunlight to sensible space heat. Consequently, the overall success of a system may be measured by the amount of heat delivered. During the heating season, most sites in the United States receive an average of about 1,000 to 1,200 Btu/sq. ft. each day. Several sites which are representative of good system operation are presented in Figure 3-1. For each of these, a typical month during the past heating season was selected *[1-16], and is illustrated in the figure. These systems provided an average of about 200 Btu/sq. ft. to the heating load, each day, or about 20 to 25 percent of the incident energy.

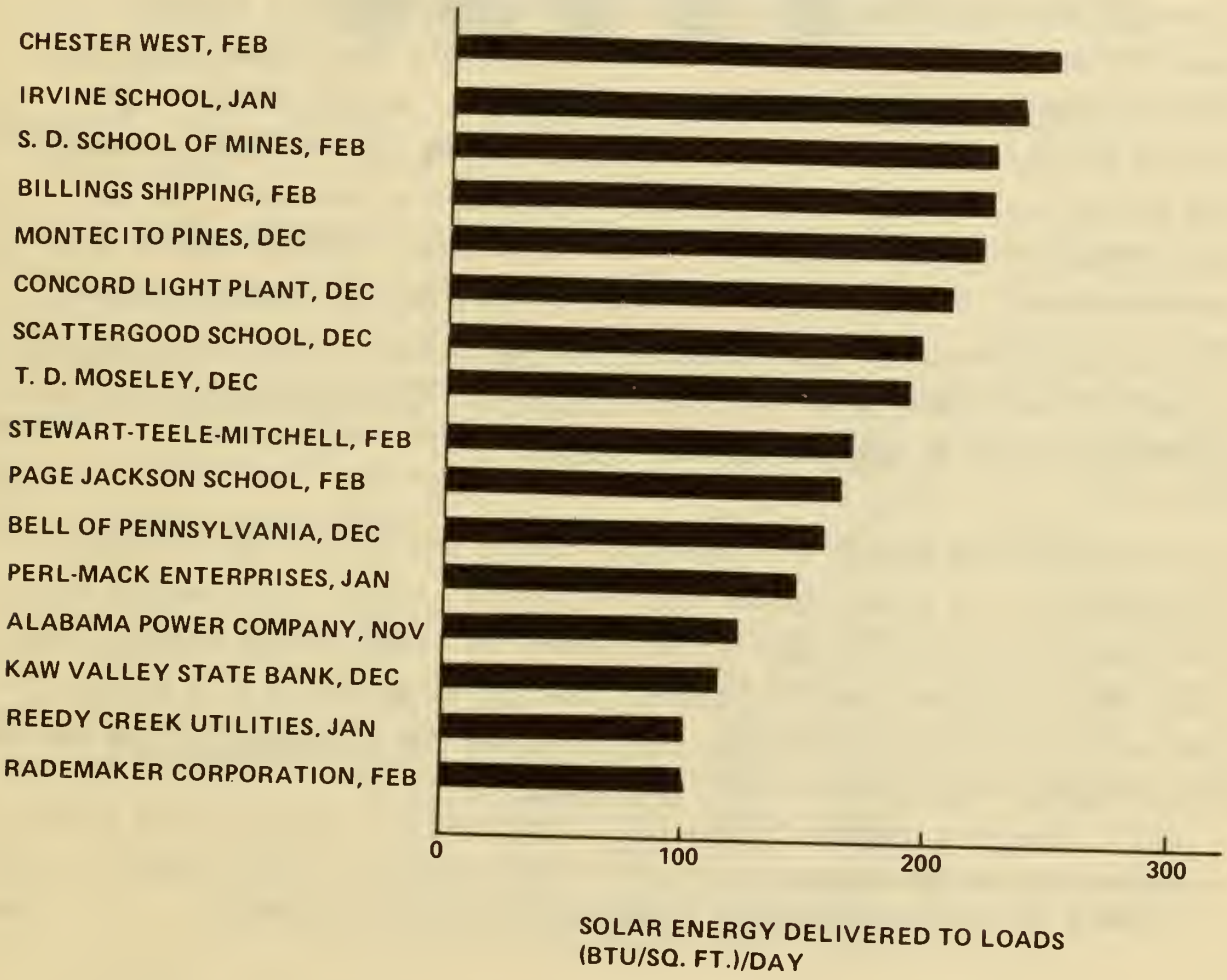

Figure 3-1. SOLAR ENERGY UTILIZATION

In addition, there was one system that provided outstanding energy conversion and transfer during December--the Irvine School site in California [17]. There was an average of about 1,230 Btu/sq. ft. available each day, and the system delivered 463 Btu/sq. ft., or 38 percent, to the load. This is a system which mainly supports space cooling and uses concentrating collectors. There is no storage. Consequently, the collector array is over-sized for the space heating requirements, and there are only small losses between collection and delivery. The implication of this is that system designers should consider the large potential benefits of using solar energy space cooling systems for space heating whenever possible. Because of the relative sizing of the collector array, it may be that only a small incremental initial cost will yield a very useful space heating system.

The solar energy system built by Chester West in Huntsville, Alabama, provides space heating (and hot water) for a single family dwelling [18]. The auxiliary heating is supplied by a heat pump. During November, the system supplied 16.8 percent of the incident energy to the load, although the system was not operational for eight days during the month (due to an inadvertent maintenance error). See Figure 3-2. Although the 16.8 percent appears low, it represents 28 percent of all the energy incident on the collectors while the collector loop was active. This figure negates the effect of the system being down for eight days. This represents quite good performance, and an adequate control system.

The solar heating system in a municipal garage and office area in Concord, Massachusetts, is an air system with a rock bin storage. This system has the characteristics of a good system, where the transport and storage losses have been minimized. During December, the system delivered 21.4 percent of the incident energy to the load; this accounted for 38 percent of the measured space heating load at the site. See Figure 3-3.

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* Numbers in brackets [] denote reference numbers in Section 6.

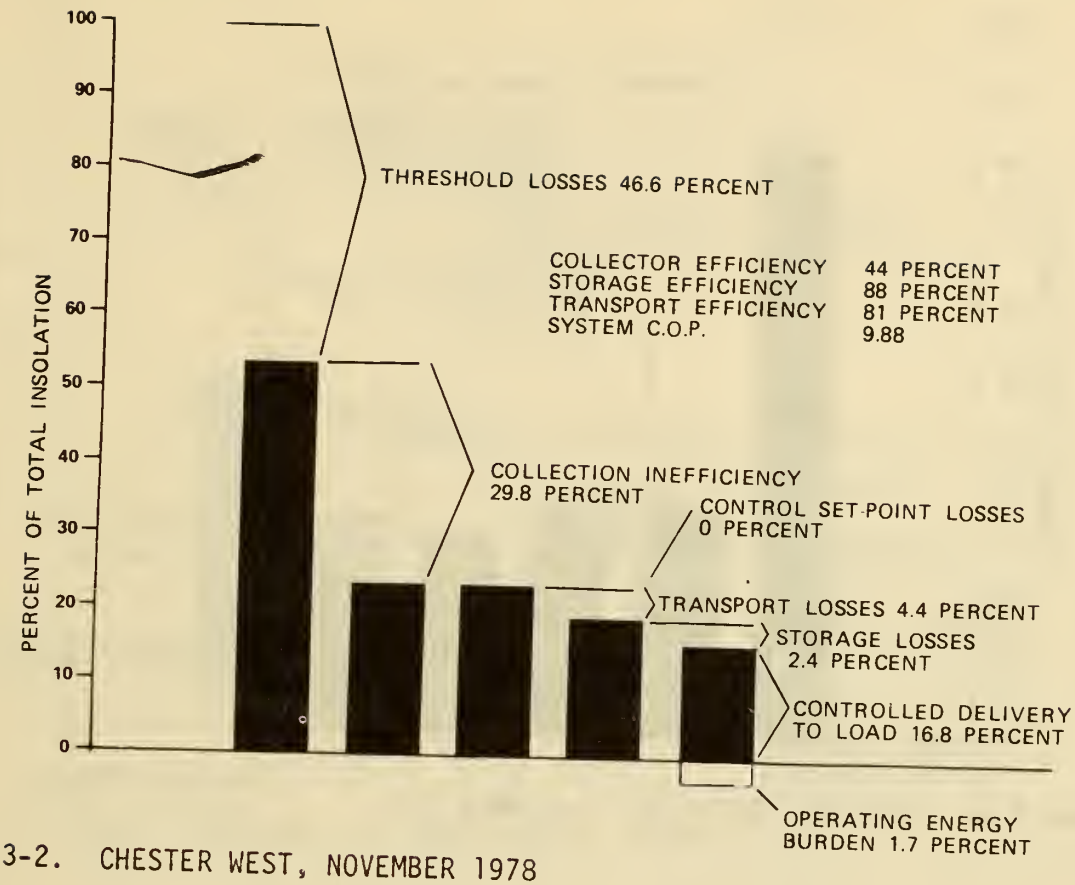

Figure 3-2. CHESTER WEST, NOVEMBER 1978

The solar energy system at Scattergood School, in Iowa, is an air system with a rock bin storage. The system supplies heating and hot water for a gymnasium, and also assists in the grain drying needs in a nearby storehouse. This system has been monitored and the performance reported through two heating seasons. During December, this system supplied 82 percent of the space heating load, which provided a substantial energy savings, see Figure 3-4. Of the total energy incident on the array, 22.8 percent was delivered to the load.

The solar energy system owned by Bell Telephone of Pennsylvania provides heating for an office building and warehouse. During December, this system provided almost 19.0 percent of the incident energy to the load. See Figure 3-5. While it was not possible to compute all of the losses in the system, it appears that the losses are quite small. The system does suffer somewhat, however, from large collection losses resulting from non-optimal control of the collector loop.

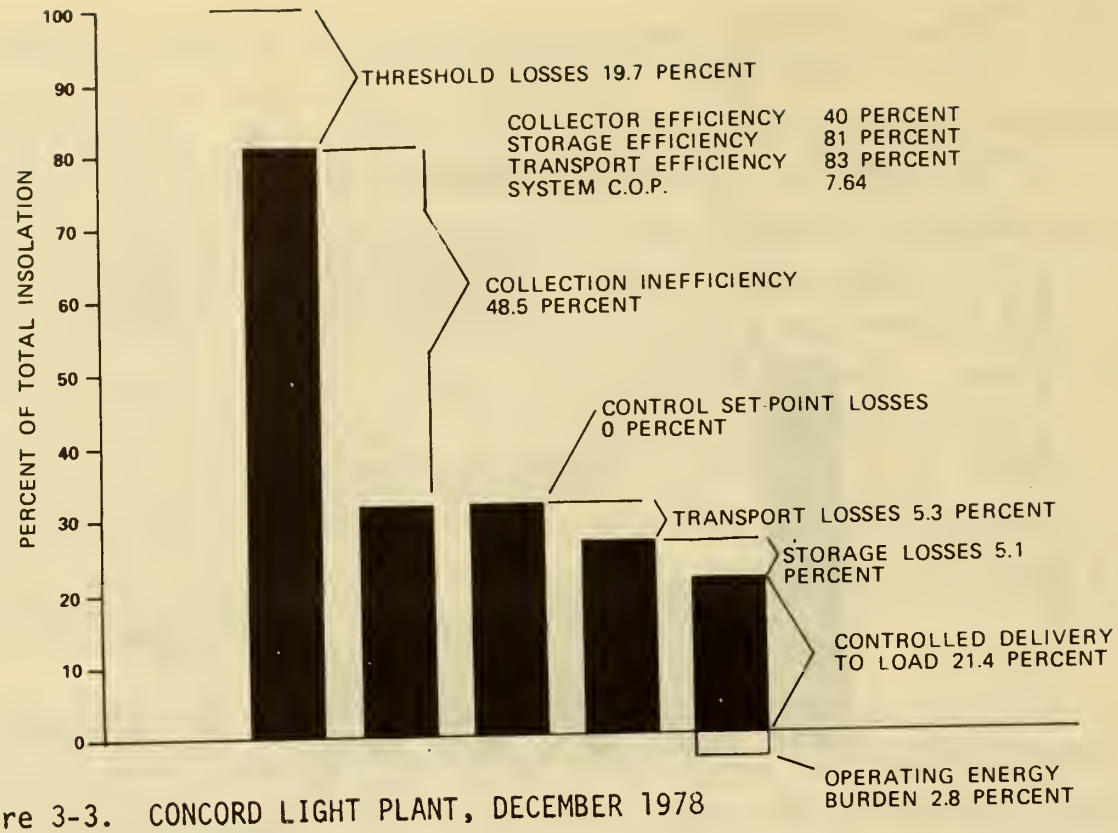

Figure 3-3. CONCORD LIGHT PLANT, DECEMBER 1978

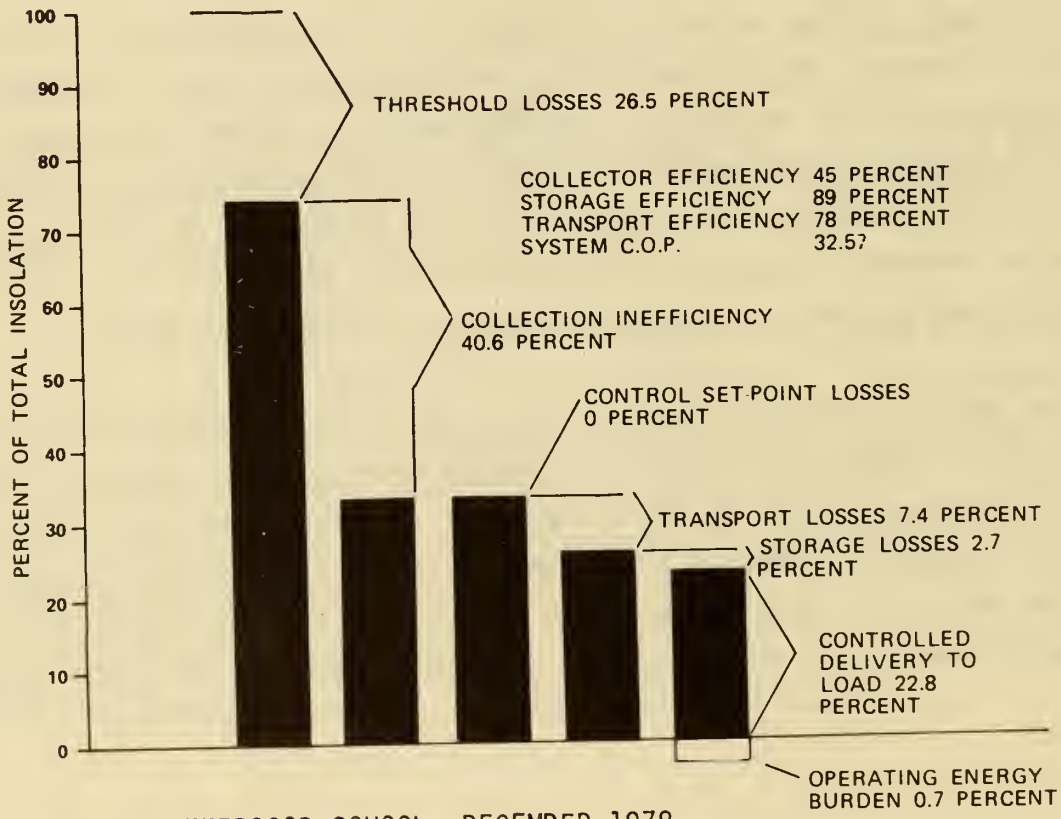

Figure 3-4. SCATTERGOOD SCHOOL, DECEMBER 1978

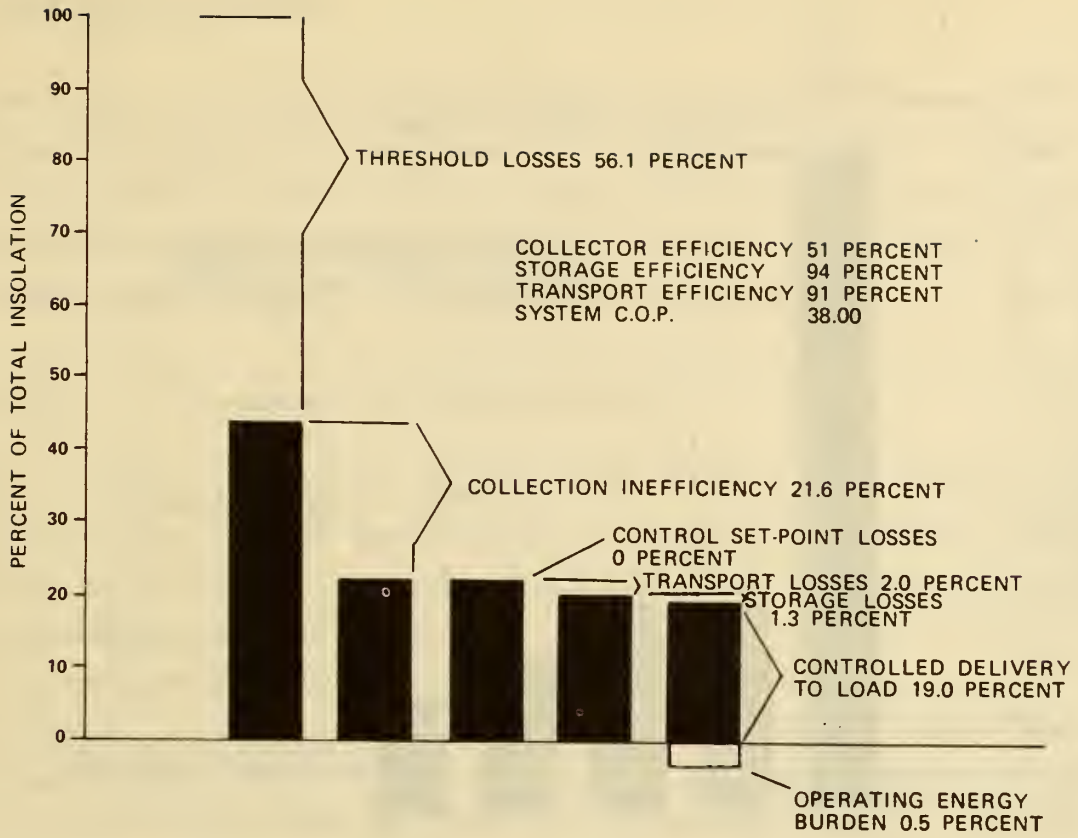

Figure 3-5. BELL TELEPHONE OF PENNSYLVANIA, DECEMBER 1978

The T. D. Moseley system in Lynchburg, Virginia, provides space heating for a small office building. This system demonstrates the benefits and performance of good transport loops between the collector and the load. Although the efficiency of the collector array was not very high, this system was still able to satisfy 27 percent of the space heating load during December. See Figure 3-6.

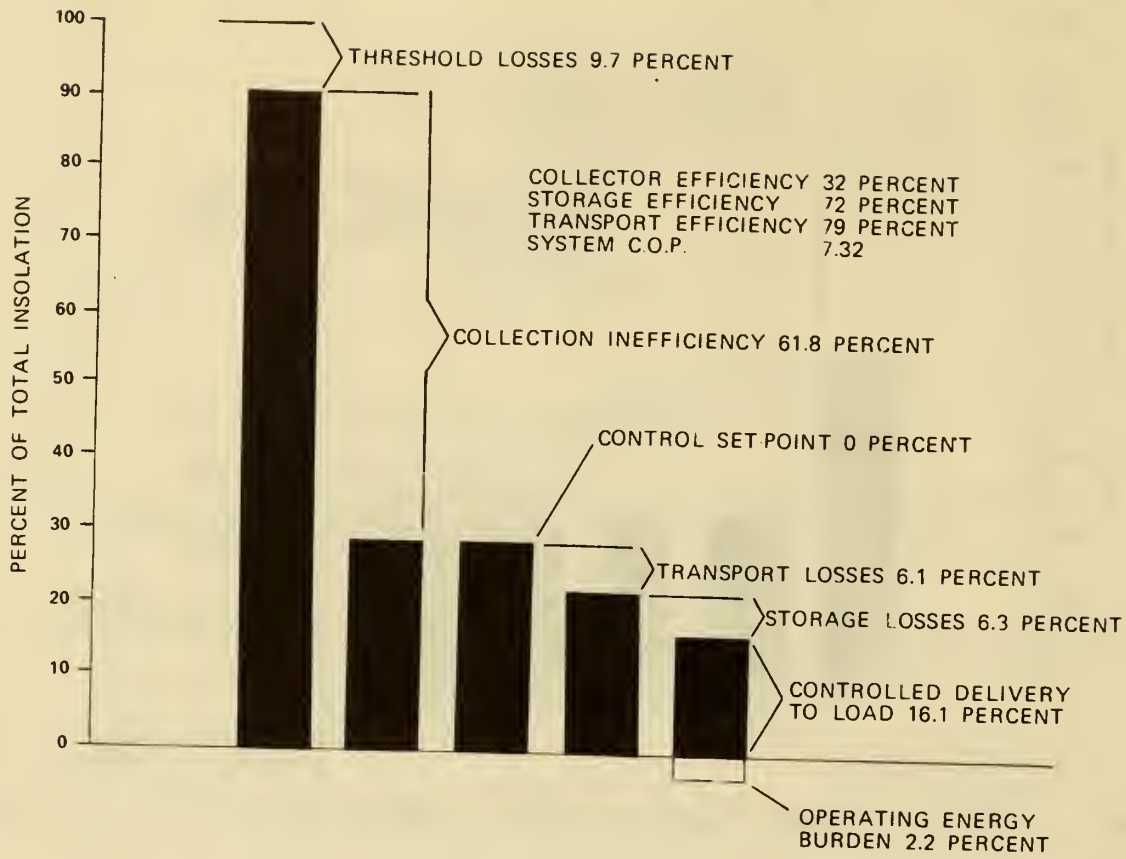

Figure 3-6. TERRELL D. MOSELEY COMPANY, DECEMBER 1978

4. PROBLEMS AND CONCERNS

Systems which are well-designed and properly installed are demonstrating that they can truly offset requirements for fossil-based fuel. However, several significant areas of concern remain. These problem areas continue to be examined, and the problems are being resolved by continued analysis and close cooperation with site-responsible personnel.

Controls

Control anomalies represent a major weakness for many solar energy systems. The problem areas include improper control set points, apparently inoperative differential controllers, and contention between the solar equipment and the auxiliary equipment.

The system at the Chester West site in Huntsville, Alabama, exemplifies the catastrophic effects of poor control, and the significant improvements which can be realized when the controls are properly adjusted. As shown in Figure 4-1, this system collected only 16 percent of the incident energy during July [19]. The control system allowed the collector loop to operate when there was little or no solar energy incident on the array. This system was expected to collect about 45 percent of the incident energy. (See Appendix B for the procedure for obtaining this estimate.) The performance for July, then, was far below normal expectation.

The anomalous behavior of this control system was discovered by monitoring the measurement data of the National Solar Data Network. The characteristics of the problem were given to the site-responsible engineer, who made appropriate adjustments to the controller.

The improved performance is apparent in Figure 4-2. During October [20], this system collected 33 percent of the incident (as compared to the estimated nominal collection of 36 percent). Not only was more energy collected, but the operating energy burden was reduced, thus increasing the net energy savings.

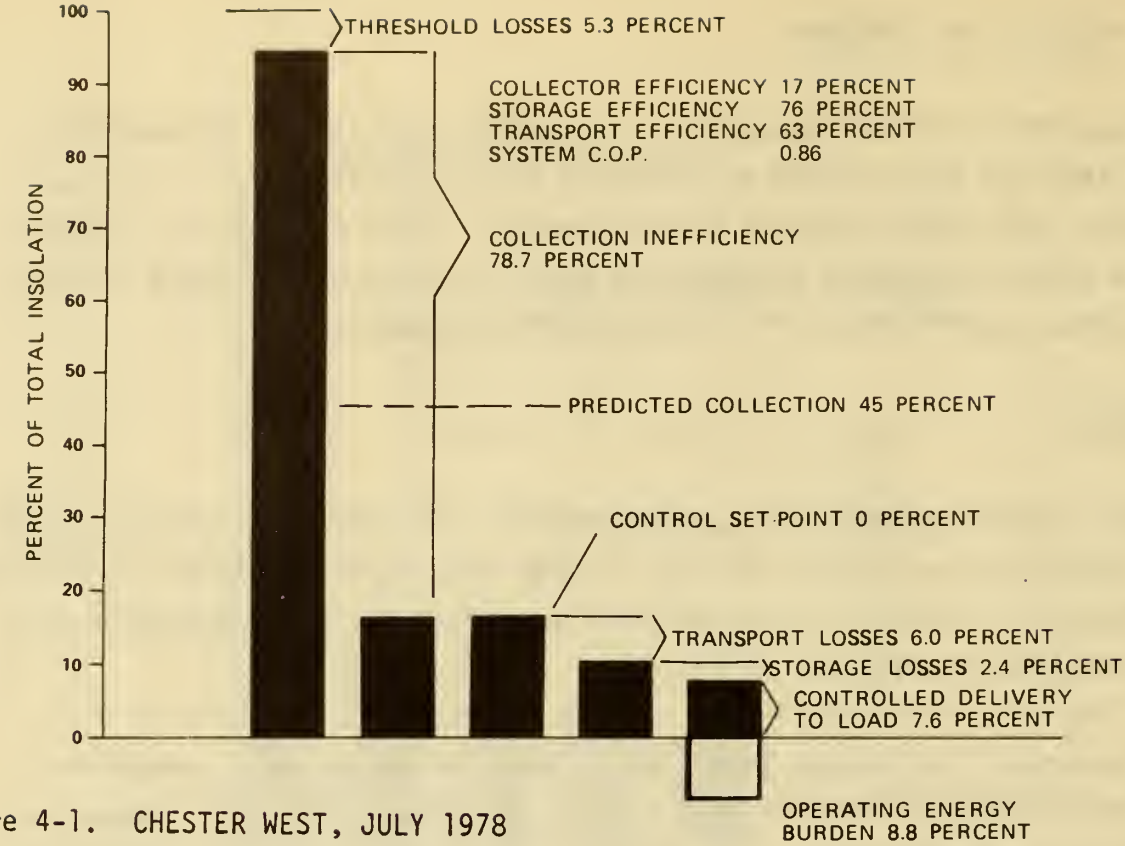

Figure 4-1. CHESTER WEST, JULY 1978

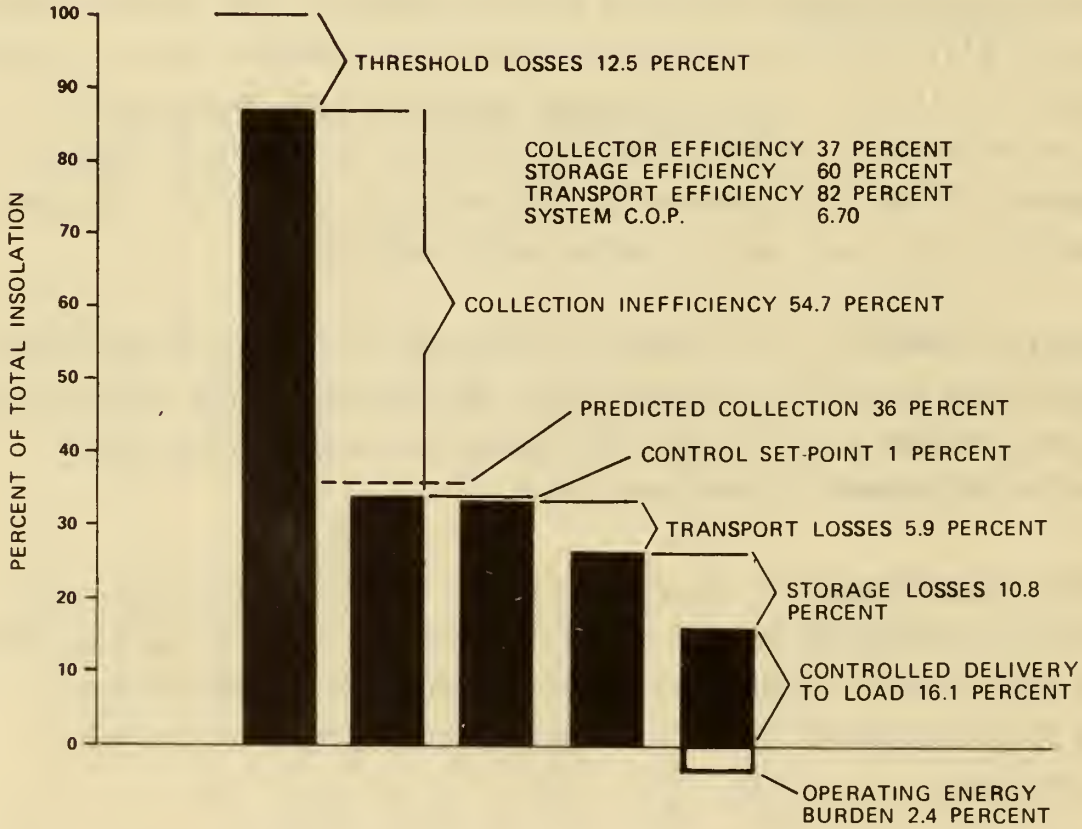

Figure 4-2. CHESTER WEST, OCTOBER 1978

Thermosiphon Effects

Thermosiphoning effects are those energy transfers which occur due to the natural convective fluid movements in the system. While these effects are often useful (so much so that the design motive force for some simple water systems is through thermosiphoning), the usual consequence for most active systems is detrimental. This is primarily due to the fact that the thermosiphoning is an uncontrolled process, and thus, if not planned, may work at odds to the active elements in the system. Two examples of thermosiphoning are presented below.

The solar system at Scattergood School is constructed such that there is a long vertical rise in the ducting from the rock bin to the outlet for the gymnasium, as illustrated graphically in Figure 4-3. Whenever the flow in the storage-to-load loop is not controlled by a blower, thermosiphoning creates a low-level flow. Cool air is drawn into the rock bin

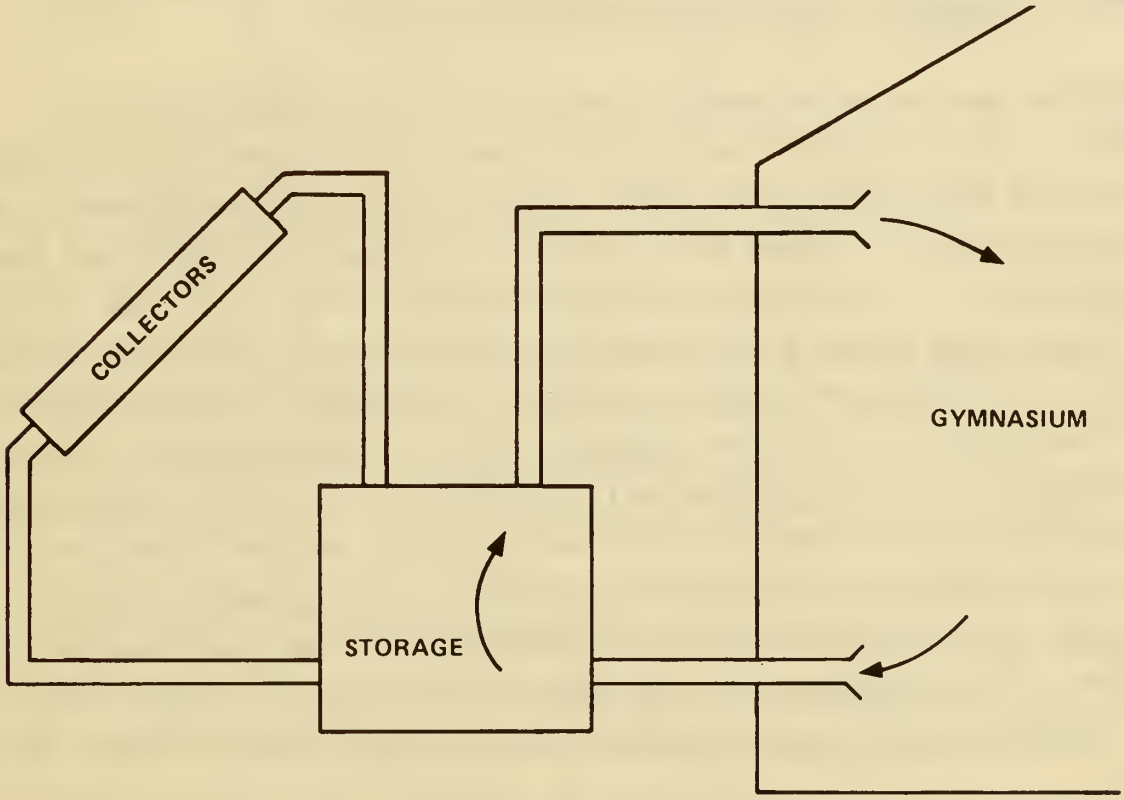

Figure 4-3. THERMOSIPHONING EFFECT AT SCATTERGOOD SCHOOL

from the gymnasium to replace warm air which rises from the rock bed to the higher level outlet. Therefore, heat is delivered to the gymnasium in an uncontrolled manner.

Scattergood has been cited earlier as a good system. This particular case of thermosiphoning is not a severe problem for this site. During winter months, the heat delivered to the gymnasium in this manner is only a small portion of the controlled delivery, and is beneficial in that it moderates the temperature swings of the gymnasium. During the transition seasons--spring and fall--the natural convective flow appears to be quite useful in supplying heat to the load. However, during warm weather, especially when the storage is being maintained at a high level for occasional cool periods, the thermosiphoning contributes unwanted heat to the gymnasium.

The overall annual effect at this site is not considered to be serious, although there may be days when additional ventilation is required to keep the gymnasium from getting uncomfortably warm.

Consider now the solar energy system at the Mount Rushmore Visitors Center in South Dakota. The collector loop of the system is illustrated in Figure 4-4. During cold nights, the collector fluid, which remains in the collectors, is cooled (and consequently becomes more dense) and flows down and out of the collector array through the inlet. This flow is the reverse of the normal collection flow for this system. The flow passes through two heat exchangers (to storage and the load), and back through the collectors to be further cooled. Some small flow apparently occurs through the load loops of the heat exchangers, also. However, the load side of the heat exchanger contain water, without any anti-freeze additive. On one occasion during the winter, the flow of cold collector fluid through the heat exchanger, due to thermosiphoning, was such that the water in heat exchanger froze and disabled the system for several days. Fortunately, there was no damage to the expensive collector array. The

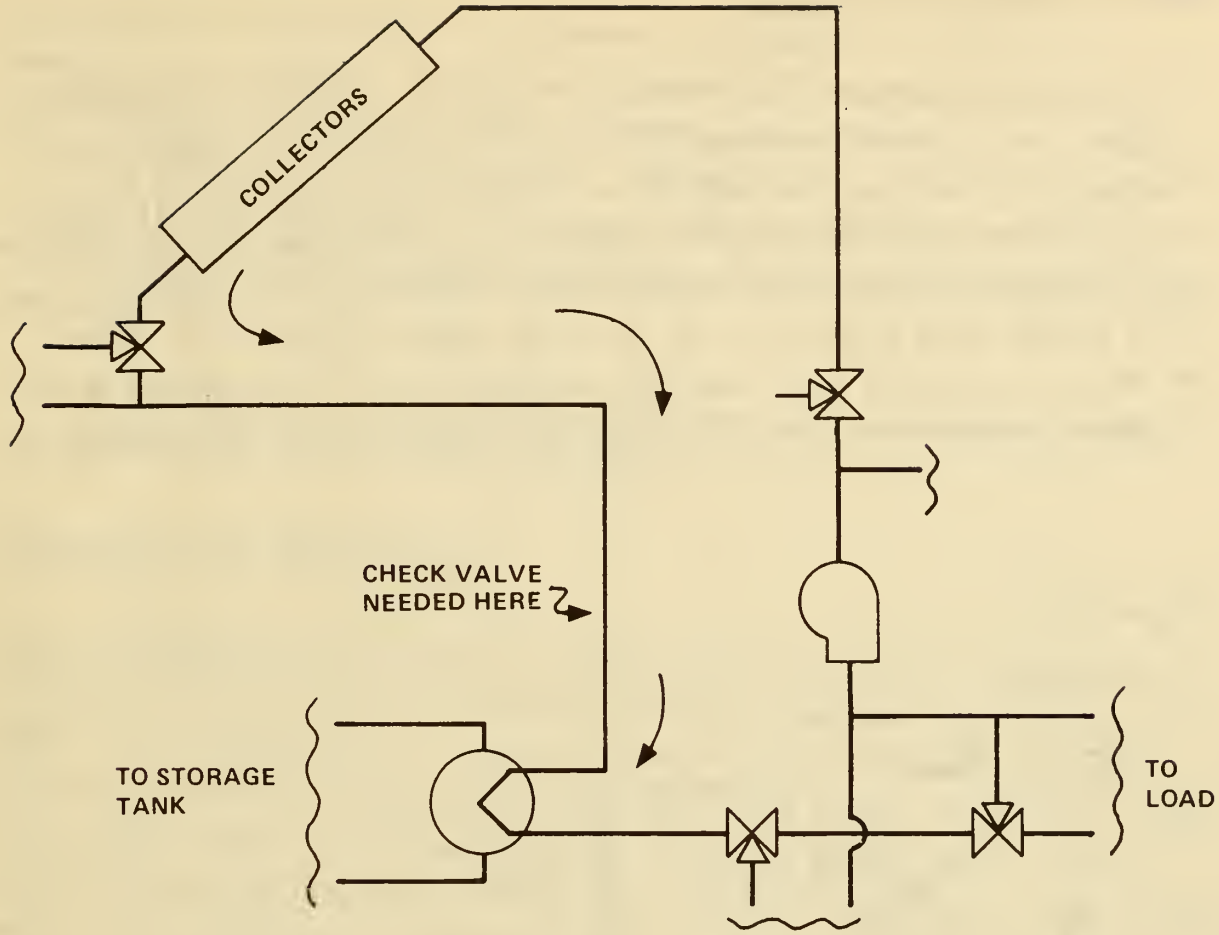

Figure 4-4. THERMOSIPHONING EFFECT AT SOUTH DAKOTA SCHOOL OF MINES

mechanism and progress of this freezing was analyzed from the measurements taken at the site via the National Solar Data Network. To prevent a re-occurrence of this problem, it was recommended that a check valve (to prohibit reverse flow) be installed at the point indicated in the figure.

The lesson to be learned from this experience, and others which are similar, is that designers and engineers must consider not only the "schematic" flow of their systems, but must give close attention to the physical lay-out of the systems, as constructed. They must be attentive to the natural forces which influence the system when it is in a presumed "quiescent" state.

Auxiliary Energy Distribution

Another problem which has been observed in several systems is illustrated in Figure 4-5. Circumstances during the winter caused this system to waste auxiliary energy. The particular system of interest here is at Trinity University in San Antonio, Texas [21]. This system was designed such that the energy delivery from the auxiliary equipment allows the auxiliary energy to be transferred to the solar energy storage tank. Also, the mechanism selected to protect the collectors from freeze damage is to circulate storage water through the collector loop whenever the ambient

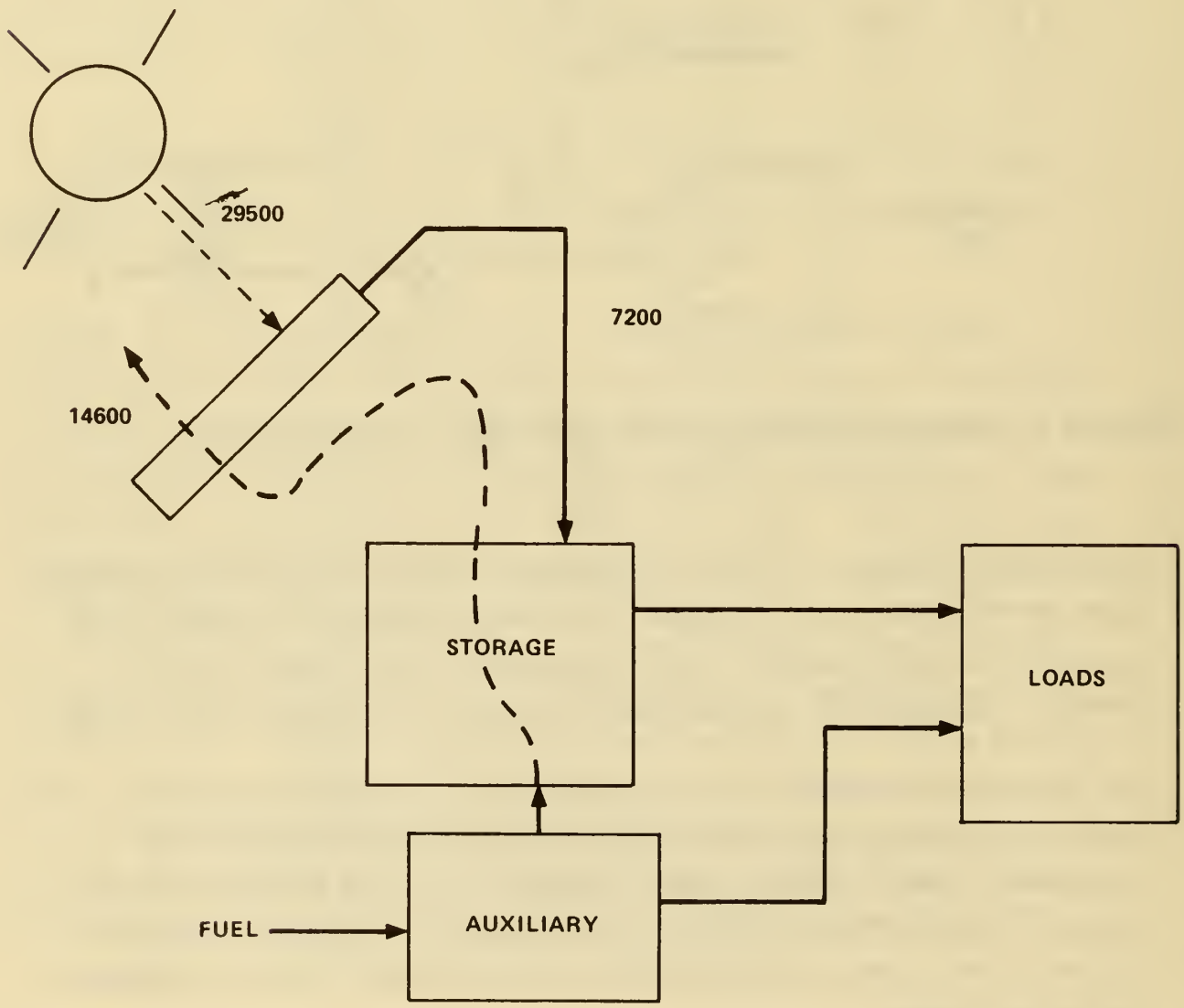

Figure 4-5. WASTE OF AUXILIARY ENERGY

temperature is dangerously low. However, and partly as a result of unusually cold weather, the system radiated 14,600 Btu/sq. ft. to the atmosphere during January, while collecting only 7,200 Btu/sq. ft. Most of this energy was auxiliary energy. The implication of this situation is that consideration should be given to alternate methods for emergency freeze protection--drain down, reduced loop flow rate, better storage/load energy management, etc.

Similar situations are created in most systems which are designed to add the auxiliary energy to the storage tank.

Interaction with Space Cooling

Here is an example of a system (see Figure 4-6) that performs acceptably for space heating, but the interaction with the space cooling function appears to be troublesome. This is the solar energy system at the Zein Mechanical site in Milwaukee, Wisconsin [22]. The system is designed around a heat pump, which, in the heating mode, transfers energy from a rock bin in an enclosed equipment room to the load. However, when in the cooling mode, heat is rejected from the heat pump to the rock bin. But the storage/collector system appears to be insufficient to reject heat from the rock bin to the atmosphere. Consequently, temperatures rise in the equipment room until heat is being conducted back into the conditioned space. This leads to an increased cooling load, even more energy rejected to the rock bin, and so on.

The lesson learned from this design is that, although the space heating performance may be acceptable, the system design and operating modes must be carefully scrutinized to insure that all design operations are harmonious and to avoid undesirable degradation of one function by another.

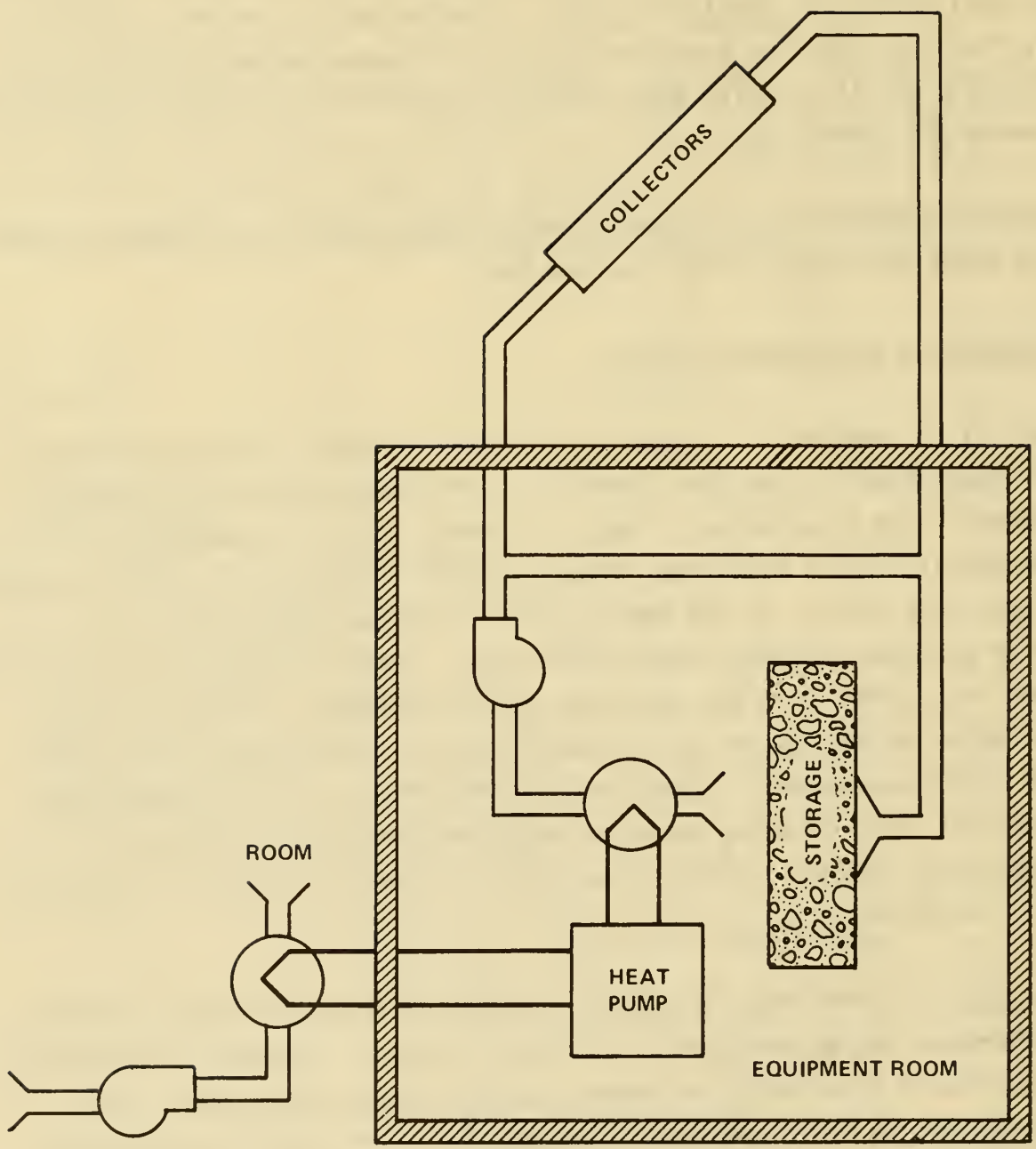

Figure 4-6. INTERACTION WITH COOLING SYSTEM

5. SUMMARY AND CONCLUSIONS

Solar space heating systems are making substantial contributions toward displacing fossil-derived fuels. This is demonstrated by the performance of several of the systems discussed in this paper. Many others, which are presently marginal, could also perform satisfactorily with relatively minor improvements in the control scheme, design, or construction of the systems.

A solar energy utilization of 20 to 25 percent appears to be attainable. Consequently, designers should strive for, and anticipate, a utilization of this size. It has been demonstrated that under favorable conditions, systems can be built which are considerably more efficient in providing energy to the load. (The utilization is defined here to be the ratio of the solar energy delivered to the load to the total energy incident upon the collector array.)

More attention should be focused on integration of solar systems with conventional systems, in general, and the control systems, in particular. These considerations seem to be the focus of most design difficulties.

6. REFERENCES

1. * "Monthly Performance Report, Chester West, February, 1979," SOLAR/1030-79/02.

2. * "Monthly Performance Report, Irvine School, January 1979," SOLAR/2021-79/01.

3. * "Monthly Performance Report, South Dakota School of Mines, February 1979,", SOLAR/2019-79/02.

4. * "Monthly Performance Report, Billing Shipping, February 1979," SOLAR/2066-79/02.

5. * "Monthly Performance Report, Montecito Pines, December 1978," SOLAR/1045-78/12.

6. * "Monthly Performance Report, Concord Light Plant, December 1978," SOLAR/2048-78/12.

7. * "Monthly Performance Report, Scattergood School, December 1978," SOLAR/2003-78/12.

8. * "Monthly Performance Report, T. D. Moseley, December 1978," SOLAR/2011-78/12.

9. * "Monthly Performance Report, Stewart-Teele-Mitchell, February 1979," SOLAR/1018-79/02.

10. * "Monthly Performance Report, Page Jackson School, February 1979," SOLAR/2036-79/02.

11. * "Monthly Performance Report, Bell of Pennsylvania, December 1978," SOLAR/2012-78/12.

12. * "Monthly Performance Report, Perl-Mack Enterprises, January 1979," SOLAR/1015-79/01.

13. * "Monthly Performance Report, Alabama Power Company, November 1978," SOLAR/2017-78/10.

14. * "Monthly Performance Report, Kaw Valley State Bank, December 1978," SOLAR/2072-78/12.

15. * "Monthly Performance Report, Reedy Creek Utilities, January 1979," SOLAR/2018-79/01.

16. * "Monthly Performance Report, Rademaker Corporation, February 1979," SOLAR/2009-79/02.

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17. * "Monthly Performance Report, Irvine School, December 1978," SOLAR/2021-78/12.

18. * "Monthly Performance Report, Chester West, November 1978," SOLAR/1030-78/11.

19. * "Monthly Performance Report, Chester West, July 1978," SOLAR/1030-78/11.

20. * "Monthly Performance Report, Chester West, October 1978," SOLAR/1030-78/10.

21. * "Monthly Performance Report, Trinity University, January 1979," SOLAR/2004-79/01.

22. * "Monthly Performance Report, Zein Mechanical, August 1978," SOLAR/1057-78/08.

23. * "User's Guide to the Monthly Performance Report of the National Solar Data Program," SOLAR/0004-78/18, February 28, 1978.

24. "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program," NBSIR 76-1137, August 1976, National Bureau of Standards.

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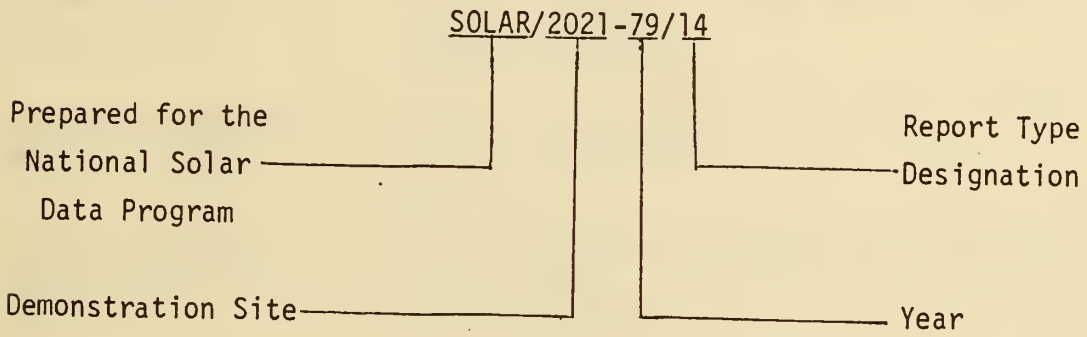

- Demonstration Site Number:

  Each Project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).

  - Solar Energy System Performance Evaluations are designated by the number 14.

  - Solar Project Descriptions are designated by the number 50.

  - Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy, Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

APPENDIX A

CHARACTERISTICS OF SOLAR SPACE HEATING SYSTEMS

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Alabama Power Co. Montevallo, AL	liquid, flat-plate, 2,340 sq. ft., PPG liquid, 8,000 gal. electric boiler
Albuquerque Western Albuquerque, NM	liquid, concentrator, 8,000 sq. ft., AWSI liquid, 57,000 gal. gas boiler
Alpha Construction Canton, OH	air, flat-plate, 428 sq.ft., Solar Energy Products Co. rock, 500 cu. ft. heat pump, electric strips
Bell of Pennsylvania Westchester, PA	liquid, flat-plate, 2,112 sq. ft., Heliotherm liquid, 6,000 gal. heat pump, electric strips, electric boiler
Billings Shipping Billings, MT	liquid, flat-plate, 1,848 sq. ft., Lennox liquid, 2,500 gal. gas boiler
Bismarck Power Co. Bismarck, ND	liquid, flat-plate, 5,000 sq. ft., Sunworks liquid, 20,000 gal. electric boiler
Blakedale Professional Center, Greenwood, SC	liquid, flat-plate, 954 sq. ft., PPG liquid, 5,000 gal. heat pump, electric strips
Bond Construction Gladstone, MO	liquid, flat-plate, 406 sq. ft., Miromit liquid, 800 gal. gas furnace, fireplace
Boulder Post Office Boulder, CO	liquid, flat-plate, 4,140 sq. ft., Lennox liquid, 6,000 gal. gas boiler
Brad Popkin Dallas, TX	air, flat-plate, 235 sq. ft., Northrup rock, 117 cu. ft. electric furnace

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Charlotte Medical Center Charlotte, NC	liquid, flat-plate, 3,950 sq. ft., General Electric liquid, 6,000 gal. electric furnace
Chester West Huntsville, AL	liquid, flat-plate, 225 sq. ft., Daystar liquid, 500 gal. heat pump, electric strips
College Houses Austin, TX	liquid, concentrator, 3,350 sq. ft., Northrup liquid, 6,000 gal. gas boiler
Columbia Gas Columbus, OH	liquid, concentrator, 2,978 sq. ft., Honeywell liquid, 5,000 gal. gas boiler
Concord Light Plant Concord, MA	air, flat-plate, 1,932 sq. ft., Sunworks rock, 1,210 cu. ft. electric strips
Dallas Recreation Center Dallas, TX	liquid, flat-plate, 3,650 sq. ft., Lennox liquid, 6,000 gal. gas boiler
Damascus Land Damascus, MD	liquid, evacuated tube, 261 sq. ft., KTA liquid, 535 gal. heat pump with solar assistance, electric strips
Davidson-Phillips Columbus, OH	air, flat-plate, 214 sq. ft., Sun Stone rock, 214 cu. ft. heat pump, electric strips
Design Construction Bigfork, MT	liquid, flat-plate, 750 sq. ft., Revere liquid, 1,300 gal. electric boiler, fireplace
Du-Cat Investments Kansas City, KS	air, flat-plate, 7,800 sq. ft., Solaron (no storage) electric furnace
First Baptist Church Aberdeen, SD	air, flat-plate, 1,253 sq. ft., Solaron rock, 700 cu. ft. electric boiler
Florida Gas Company Winter Springs, FL	liquid, flat-plate, 714 sq. ft., Chamberlain liquid, 1,350 gal. gas boiler

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Frank Chapman New Haven, CT	air, flat-plate, 1,070 sq. ft., on-site fabrication rock, 2,000 cu. ft. electric strips, fireplace
Hamden Apartments Hamden, CT	liquid, flat-plate, 2,600 sq. ft., Solar Products Manufacturing Corporation liquid, 8,000 gal. electric furnace
Harney Lumber Co. #87 Rapid City, SD	liquid, flat-plate, 287 sq. ft., Miromit liquid, 1,800 gal. electric furnace
Harney Lumber Co. #88 Rapid City, SD	liquid, flat-plate, 287 sq. ft., Miromit liquid, 1,800 gal. electric furnace
Homes by Marilynn Albuquerque, NM	liquid, flat-plate, 310 sq. ft., Revere liquid, 1,000 gal. heat pump, electric strips
Howard's Grove School Howard's Grove, WS	air, flat-plate, 2,685 sq. ft., Sun Stone rock, 1,500 cu. ft. oil boiler
Irvine School Irvine, CA	liquid, evacuated tube, 4,950 sq. ft., Owens-Illinois (no storage) gas boiler
J. D. Evans #A Columbia, MD	liquid, flat-plate, 374 sq. ft., Revere liquid, 550 gal. heat pump, electric strips
J. D. Evans, #B Columbia, MD	liquid, flat-plate, 374 sq. ft., Revere liquid, 550 gal. heat pump, electric strips
John Byram Shawnee, KS	air, flat-plate, 195 sq. ft., Solaron rock, 98 cu. ft. gas furnace
Joseph Real Estate West Springfield, MA	air, flat-plate, 426 sq. ft., Comtemporary Systems rock, 426 cu. ft. gas furnace
Kaw Valley State Bank Topeka, KS	liquid, evacuated tube, 1,253 sq ft., General Electric liquid, 1,100 gal. gas boiler

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Kirtland AFB Abuquerque, NM	liquid, flat-plate, 9,930 sq. ft., Ray-pak liquid, 20,000 gal. heat pump, electric boiler
Lake Valley Firehouse, Tahoe Paradise, CA	liquid, flat-plate, 352 sq. ft., Western Energy liquid, 1,200 gal. gas boiler
Landura Corporation Stayton, OR	liquid, flat-plate, 318 sq. ft., Sunworks liquid, 2,500 gal. heat pump with solar assistance, electric strips
Lincoln Housing Lincoln, NE	liquid, flat-plate, 1,297 sq. ft., Chamberlain liquid, 5,330 gal. gas boiler
Loudoun County Schools Leesburg, VA	liquid, flat-plate, 1,225 sq. ft., Southwest Ener-Tech liquid, 3,056 gal. electric boiler
LSU Field House Baton Rouge, LA	liquid, flat-plate, 5,700 sq. ft., Lennox liquid, 10,000 gal. gas boiler
Lutz-Sotire Stamford, CT	liquid, flat-plate, 2,561 sq. ft., Sunworks liquid, 6,000 gal. heat pump with solar assistance, electric boiler
Matt Cannon Gainesville, FL	liquid, flat-plate, 597 sq. ft., Gulf Thermal liquid, 1,000 gal. electric furnace
M. F. Smith Associates Jamestown, RI	liquid, flat-plate, 512 sq. ft., Solar Homes liquid, 3,150 gal. heat pump with solar assistance, electrical booster
Montecito Pines Santa Rosa, CA	liquid, flat-plate, 880 sq. ft., Sunburst liquid, 2,000 gal. gas boiler
Moulder Corporation Greenwood, IN	air, flat-plate, 704 sq. ft., Solar Space Energy Products Co. rock, 850 cu. ft. electric furnace
Olympic Engineering Richland, WA	liquid, flat-plate, 6,098 sq. ft., General Electric liquid, 9,000 gal. heat pump with solar assistance, electric strips

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Ortiz & Reill, #5 Escondido, CA	liquid, flat-plate, 196 sq. ft., Southwest Ener-Tech liquid, 750 gal. gas furnace, fireplace
Ortiz & Reill, #8 Escondido, CA	liquid, flat-plate, 196 sq. ft., Southwest Ener-Tech liquid, 750 gal. gas furnace, fireplace
Padonia Elementary Sch. Cockeysville, MD	liquid, concentrator, 3,350 sq. ft., AAI liquid, 10,000 gal. oil boiler
Page-Jackson Elementary School, Charles Town, WV	liquid, flat-plate, 11,000 sq. ft., PPG liquid, 20,000 gal. oil boiler
Perl-Mack Denver, CO	liquid, flat-plate, 470 sq. ft., Miromit liquid, 945 gal. gas furnace
Phillips-Kauric I St. Matthews, SC	liquid, flat-plate, 640 sq. ft. Revere liquid, 750 gal. heat pump, electric strips
Phillips-Kauric II St. Matthews, SC	liquid, flat-plate, 640 sq. ft., Revere liquid, 750 gal. heat pump, electric strips
Public Service of New Mexico, #7 Albuquerque, NM	air, flat-plate, 150 sq. ft., Solar Seven Industries rock, 225 cu. ft. electric furnace
Public Service of New Mexico, #21 Albuquerque, NM	air, flat-plate, 150 sq. ft., Solar Seven Industries rock, 225 cu. ft. electric furnace
Rademaker Corporation Louisvill, KY	liquid & air, flat-plate, 240 & 195 sq. ft., Solar Development & Solaron liquid & rock, 560 gal. & 110 cu. ft. gas furnace
Radian Corporation Austin, TX	liquid, concentrator, 1,380 sq. ft., Northrup liquid, 1,500 gal. gas furnace

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Randolph AFB San Antonio, TX	liquid, flat-plate, 15,500 sq. ft., Ray-pak liquid, 25,000 gal. gas boiler
Reedy Creek Utilities Lake Buena Vista, FL	liquid, concentrator, 3,840 sq. ft., AAI liquid, 10,000 gal. (no auxiliary source)
RHRU Clemson Clemson, SC	air, flat-plate, 381 sq. ft., on-site fabrication rock, 1,161 cu. ft. heat pump, electric strips
Salisbury House Salisbury, NC	liquid, trickle, 640 sq. ft., on-site fabrication rock, 500 cu. ft. oil water heater
Saddle Hill Trust, Lot #36 Needham, MA	liquid, flat-plate, 293 sq. ft., Daystar liquid, 750 gal. oil furnace
Scattergood School Westbranch, IA	air, flat-plate, 2,496 sq. ft., Solaron rock, 1,300 cu. ft. gas furnace
Shenandoah Community Center, Shenandoah, GA	liquid, flat-plate, 9,778 sq. ft., Revere liquid, 17,500 gal. gas boiler
Sir Galahad Virginia Beach, VA	liquid, flat-plate, 640 sq. ft., Revere liquid, 1,500 gal. heat pump, electric strips
S. D. School of Mines Keystone, SD	liquid, flat-plate, 2,000 sq. ft., Lennox liquid, 3,000 gal. oil furnace
Spence-Urban Des Moines, IA	liquid, flat-plate, 429 sq. ft., Solaron rock, 215 cu. ft. heat pump, electric strips
State of Florida Yulee, FL	liquid, concentrator, 2,840 sq. ft., Northrup liquid, 6,000 gal. oil furnace
Stewart-Teele-Mitchell Malta, NY	liquid, flat-plate, 432 sq. ft., Lennox liquid, 1,000 gal. gas furnace
Suntech Homes Chester, NY	air, flat-plate, 128 sq. ft., Solar Shelter rock (brick), 360 cu. ft. heat pump, electric strips

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Technology Property Trust, Burlington, MA	liquid, flat-plate, 1,872 sq. ft., Daystar liquid, 6,000 gal. electric strips
Telex Communication Blue Earth, MN	liquid, flat-plate, 12,686 sq. ft., Solar Corp. of America liquid, 20,000 gal. electrical furnace, electrical strips
Tempe Union High School Tempe, AZ	liquid, flat-plate, 20,621 sq. ft., Southwest Standard liquid, 47,000 gal. electric boiler
T. D. Moseley Lynchburg, VA	liquid, flat-plate, 400 sq. ft., on-site fabrication liquid, 2,000 gal. gas boiler
Towns Elementary School Atlanta, GA	liquid, flat-plate, 10,360 sq. ft., PPG liquid, 45,000 gal. gas boiler
Trinity University San Antonio, TX	liquid, concentrator, 16,080 sq. ft., Northrup liquid, 40,000 gal. gas boiler
Troy-Miami Library Troy, OH	liquid, evacuated tube, 3,264 sq. ft., Owens-Illinois liquid, 5,000 gal. electric furnace & strip heaters
Twin City Builders Coos Bay, OR	liquid, flat-plate, 234 sq. ft., Revere liquid, 1,250 gal. electric furnace
Upton Center Baltimore, MD	liquid, flat-plate, 3,100 sq. ft., PPG liquid, 20,000 gal. heat pump with solar assistance, electric boiler
Walnut Ridge Washington, PA	air, flat-plate, 620 sq. ft., Kalwall rock, 1,100 cu. ft. heat pump with solar assistance, electric strips
Washington Natural Gas Seattle, WA	air, flat-plate, 591 sq. ft., Solaron rock, 273 cu. ft. gas furnace

SITE LOCATION	COLLECTOR STORAGE AUXILIARY HEATING EQUIPMENT
Waverly Homes #13 Westminster, CO	air, flat-plate, 351 sq. ft., Sunglow rock, 176 cu. ft. gas furnace
Waverly Home #14 Westminster, CO	air, flat-plate, 312 sq. ft., Solaron rock, 312 cu. ft. gas furnace
Zein Mechanical Milwawkee, WI	air, flat-plate, 384 sq. ft., Solaray rock, 400 cu. ft. heat pump with solar assistance, electric strips

APPENDIX B

TECHNIQUE FOR ESTIMATION OF NOMINAL SOLAR ENERGY COLLECTION

In order to assess the real performance of a collector array, it is frequently necessary to know how much solar energy a particular array should have collected under the prevailing conditions. This can be compared to the actual energy collection experienced during some period--a month, for example. This is especially useful in the investigation of control anomalies. The procedure outlined in the following discussion will provide the needed comparative data with an error of less than 10 percent. The intention here is to be able to make this estimation from the data published in the regular monthly reports [23 and 24] on sites in the National Solar Data Network, although some additional information may be required, especially to determine the collector parameters.

Two steps are required. First, one must determine the collector array characteristics for the particular installation. In general, these should be determined from the measured data, since the values of $F_R\tau\alpha$ and F_RU_L exhibited by the array as installed and operated may be significantly different from the manufacturer's specification for a single panel measured under laboratory conditions.

Several sets of data should be selected which represent distinct hours of operation during which the system was continuously collecting. The data needed is ambient temperature, insolation, collector inlet temperature (or storage temperature), collector outlet temperature, and collector loop flow rate. The operating points and corresponding efficiencies are then plotted to obtain a graphical solution for the collector parameters. It is good practice to obtain widely separated operating points to firmly establish the characteristic straight line; such points can usually be selected by observing the relative insolation levels. Two additional parameters must be estimated from the measured performance data--the threshold efficiency and the average daily "on-time." From the monthly report, the collector threshold efficiency, F_c, can be calculated as the ratio of the

operational incident energy to the total incident energy on days of apparently good collector loop operation. Typically, this is about 0.80 to 0.90. The average daily collector operating time, H_c, can be estimated from the ECSS operating energy on days of good collector loop operation. This is usually between six and eight hours.

These parameters are sufficient to define a daily collection equation, as follows:

$$Q_d = A_c[F_c(F_R\tau\alpha)I_d - H_c(F_RU_L)(T_{ci}-T_{da})]$$

where A_c is the collector array area, and I_d is the daily insolation in the collector plane. Suitable values of the collector inlet temperature, T_{ci}, can be obtained from the daily average storage temperature, and the daytime ambient temperature, T_{da}, is tabulated in the enviromental data of the monthly report.

This equation should be exercised for each day in the month (or period of interest) and the results summed to obtain the predicted normal energy collection under the prevailing weather conditions and experienced operating characteristics of the collector system.

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